RESEARCH BULLETIN 914 JUNE 1962

RELATIONSHIPS BETWEEN

- FORAGE GROWTH STAGE
- DIGESTIBILITY
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and

- MILK PRODUCTION

in

DAIRY COWS

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6/62/3.5M

RELATIONSHIPS BETWEEN FORAGE GROWTH STAGE, DIGESTIBILITY, NUTRIENT INTAKE, and MILK PRODUCTION in DAIRY COWS

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Knowledge of the nutritive value of forages has become a matter of economic significance to dairymen developing high producing herds. Nutrients most often lacking in the daily quantity of feed consumed by dairy cows are digestible carbohydrates for energy, nitrogen for protein synthesis, and calcium and phosphorus. Consequently, the content of these nutrients is a useful criterion for appraising roughage quality even though gross chemical content of forages cannot be used as a sole criterion for estimating productive value in terms of milk yield of a dairy herd.

It is the purpose of this paper to show: 1) How these nutrients varied in mixed-grass-legume-meadow crops with advancing stages of maturity; and 2) how plant maturity was related to the utilization of these nutrients by dairy cows.

REVIEW OF PRESENT INFORMATION

The cell walls of forage plants are made up of a mixture of polysaccharide derivatives which are largely digested in the rumen. The major component of these polysaccharide derivatives in the plant cell wall is cellulose. Lignin is an indigestible non-polysaccharide material that may also be incorporated into the cell wall tissue of mature plants. The remaining polysaccharides and related carbohydrates in the plant tissue are of equal or greater importance than cellulose as a source of energy to ruminants. Because growth and aging of plants are interrelated with forage quality, these plant carbohydrates are being listed here in the context of a simplified discussion of plant growth.

Plants grow through cell division. After nuclear division, polysaccharides are laid down along a definite line between the two new nuclei which is called the cell plate. The initial materials laid down are large amounts of pectin or calcium pectate. Some hemicellulose and xylan are usually present along with a submicroscopic frame of cellulose. The cell plate which expands to meet the walls of the parent cell becomes the middle lamella which serves to bind the two daughter cells. In maturing plants the pectins are partly replaced by lignin. Also present in older plants are pentosans, xylan and uronic acid containing material (12).

By 1900 Kellner (16) had studied the nutritive value of forages and noted the lowered digestibility caused by encrusting substances formed at maturation. Significantly, by the same time he had shown that "delignified" cellulose was equally as valuable as starch for fattening steers. Since these early studies, detailed reviews and studies of numerous investigations have been published on the effects of plant maturation in digestibility (11, 14), feed intake (22) and milk production (13, 22). From Reid's study it was shown that growth stage is the major determinant of TDN and metabolizable energy values of forage crops, provided the forage has its normal complement of leaves.

Digestibility in cattle was used by Reid *et al.* (23) to compute a regression on cutting dates. In these cattle which had been fed forages grown in New York, dry matter digestibility declined at the rate of 3.3 percentage units per week. When all varieties of forages used were included, the range was described by Reid as extending over 8.3 percentage units. Using forage crops grown in the vicinity of Betsville, Kane and Moore (15) computed a different regression equation. The weekly decline was 2.8 percentage units, or, in comparison to the New York experiments, a slower decline in digestibility with advancing cutting dates. Martz *et al.* (20) found that the digestibility of alfalfa-bromegrass dropped from 79 percent to 58 percent between May 11 and July 5 in Indiana.

Ely *et al.* (11) made a comprehensive study of the carbohydrates in orchard grass at four stages of growth. It is noteworthy that all of the principal fractions, cellulose, hemicellulose, pentosans, and undetermined carbohydrates declined in digestibility with advancing stages of growth.

Kamstra (14) concluded that lignin was the major factor limiting *in vitro* cultures of rumen microorganisms from digesting cellulose of grass plants completely. Quicke *et al.* (21) found *in vitro* digestion of cellulose in timothy to be inversely correlated with the lignin content. More recently Dehority and Johnson (9) showed that physical disintegration of lignin by ball-milling alfalfa cut at three stages of growth and timothy cut at four different stages of growth enhanced cellulose, pentosan and uronic acid digestion markedly. In fact, after ball-milling, the cellulose fractions of each growth stage or cutting date were digested equally well (approximately 87 percent of the cellulose present in 48 hours).

A large group of experiment station workers are presently engaged in developing the artificial rumen technique as a tool to measure forage quality. Reports made to date show that this is a reliable method (1, 10, 21). Also, determination of rate of cellulose digestion *in vitro* offers a way to compute reliable estimates of feed intake (7, 10).

EXPERIMENTAL PROCEDURES AND RESULTS

Digestibility, feed intake, milk production, and nitrogen, calcium and phosphorus balances were determined in conjunction with forage utilization studies to evaluate the effects on nutritive value, advancing maturity or length of growing period. In all, 83 digestion trials were carried out.

Samples of feed were obtained daily from each feeding and stored under refrigeration until composited for chemical analysis.

Dry matter determinations were made on green roughage, hay and grain by drying 24 hours at 100° C. Silage dry matter was determined by toluene distillation. Nitrogen determinations were made by Kjeldahl procedure. Cellulose was determined by the method of Crampton and Maynard (8).

Calcium was determined by the method of Clark and Collip (4) and phosphorus by the modified colorimetric method of Briggs (3) using samples that were previously wet ashed with a mixture of five parts nitric acid and one part perchloric acid and adjusted to approximately pH 4.

Volatile fatty acid production and cellulose digestion were determined *in vitro* on part of the forages during a 22-hour fermentation period with rumen fluid using the procedure of Linke (18) for volatile fatty acid and Crampton and Maynard (8) for cellulose. The rumen fluid used for inoculating the fermentation flasks was obtained from young heifers fed alfalfa hay and grain, and diluted with mineral buffer described by Bentley *et al.* (2).

Digestion and balance trials were carried out in conjunction with feeding trials. The cows were kept in the stalls they normally occupied. Procedures for the separate collection of urine and feces have been described previously (5).

EXPERIMENT 1.—The Nutritive Value of Forages at Various Stages of Maturity and Its Relationship to the Amount of Digestible Nutrient Intake and Level of Milk Production.

Feeding trials were begun on May 16, 1959, with twelve cows fed freshly chopped alfalfa-grass (soilage) free choice as the only roughage. A more complete description of the meadows used, the species growing in them and the stage of growth are presented in Table 1. Five-day digestion trials were initiated on the following dates: May 26, June 1, June 8, June 15 and June 22. Two pairs of cows were used alternately for the various digestion periods. Later digestion trials were carried out using second growth alfalfa soilage after a 39-day growing period and third growth alfalfa after a 35-day growing period. Two other cows receiving a limited amount of grain—a mixture of corn, oats and soybean oil meal—were used for digestion studies at monthly intervals.

Details of the results are presented in Table 2. The interrelationships of nutrient content of the forage, digestibility by the cows, and milk production at different dates through the summer are shown graphically in Figure 1.

The four major requirements by dairy cows for milk production—digestible nutrients for energy, nitrogen for protein, calcium and phosphorus—were deficient in these cows, and became increasingly deficient during the period of first-growth feeding. Milk production declined markedly. The improved nutrition of the cows after feeding of second-growth alfalfa was reflected in a rise in milk production. The extent to which limited grain feeding offset the effects of decreasing nutritive value of the forage is shown in Table 3. *In vitro* digestion data are presented in Table 4. *In vitro* and *in vivo* cellulose digestibility are compared to the feed intake per unit of metabolic size, the nutritive value index, and volatile fatty acid production. Nutritive value indices for the forages of various cutting dates were calculated according to the procedure outlined by Crampton *et al.* (7).

EXPERIMENT 2.—Further Studies of Digestion Coefficients and Digestible Dry Matter Intakes Obtained with Dairy Cows Fed Legume-Grass or Alfalfa as Soilage, Silage or Hay.

During the course of various experiments on the utilization of forage crops by dairy cows, it was possible to carry out digestion trials on first-cutting legume-grass and second and third-cutting alfalfas for which the date of harvest or length of growing period was known. Because these digestion coefficients seemed valuable in estimating the general effect of maturity on the nutritive value of forages, average digestibilities for each forage have been collected and are shown in

Table 1.—Maturity with Respect to Blooming of Forage Plants Chopped for Cows on Cutting Date Experiment

Forage Plants	Dates of cutting (1st day of digestion trials)						
	5/25/59	6/1/59	6/8/59	8/15/59	6/22/59	7/24/59	8/17/59
Alfalfa	Pre-bud *	Budded *	Budded	Early bloom	Full bloom *	½ Bloom*	Early Bloom *
Brome grass	Early head *	Fully headed *	——	——	Heads turned straw color *	——	——
Timothy	Boot	Emerging heads	Early heading pre-bloom *	Fully headed pre-bloom *	Full bloom *	——	——
Ladino	Pre-bloom	Pre-bloom	Pre-bloom *	Early bloom *	——	——	Full bloom
Orchard grass	Fully headed	Early to full bloom	——	Seed in milk stage *	——	——	——
Tall Fescue	Early headed	Pre-bloom fully headed	——	——	——	——	——
Kentucky bluegrass	Headed pre-bloom	Full bloom	——	Seed early dough stage	——	——	——
Red clover	——	——	Early bloom	——	——	——	——
Birdsfoot trefoil	——	——	——	Early bloom	——	——	——
Weeds	Present	Present	Present	Present	Present	——	——

*Refers to principal plants contained in the chopped forage for indicated date.

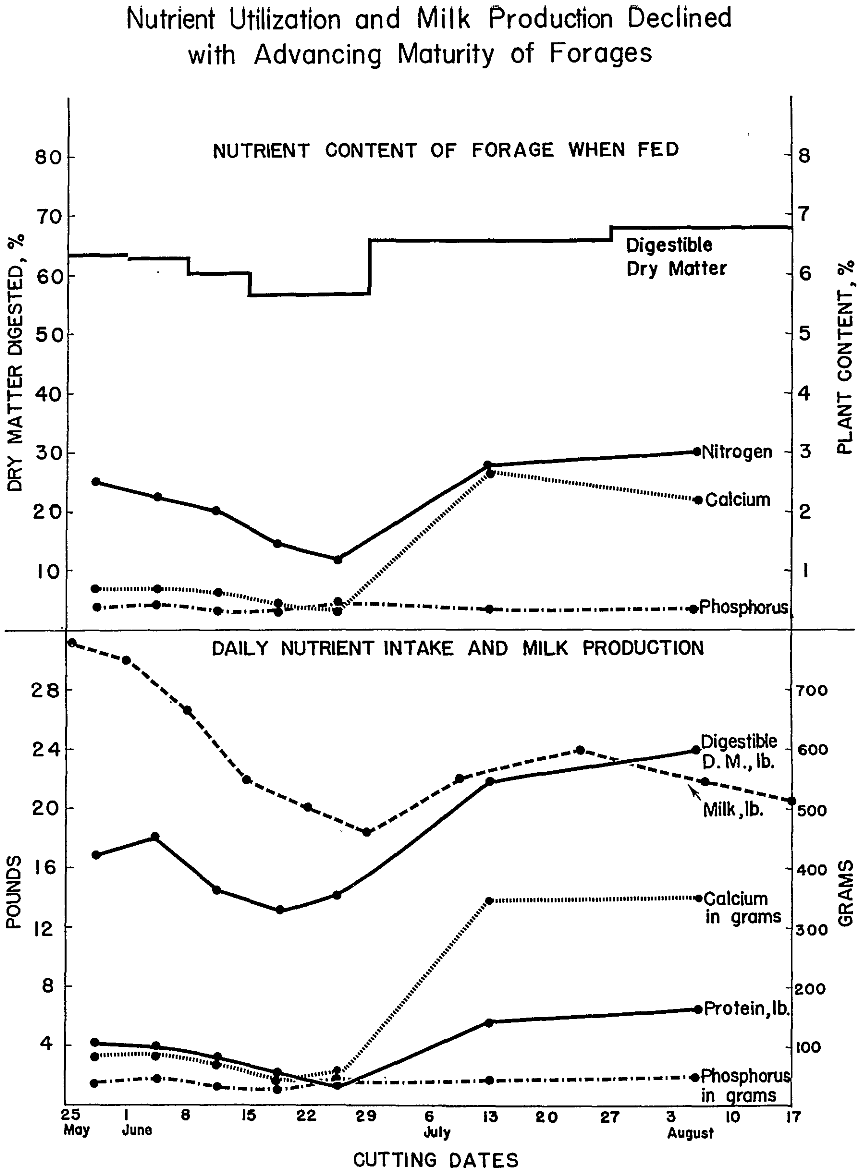

Fig. 1.—The Changes in Nutrient Utilization and Milk Production with Advancing Maturity of Legume-Grass Forage and After Changing to Second and Third Cuttings.

Table 2—Digestibility and Nutrient Utilization by Dairy Cows of Mixed Legume-Grass Forages Harvested at Different Times During the Summer of 1959

Cutting Date	Growth Stage	Milk Production	Dry Matter Digested	Dig. D.M. per 1000 lb. B.W.	Protein Digested	Nitrogen Balance	Calcium Digested	Calcium Balance	Phos. Digested	Phos. Balance
		(lb.)	(%)	(lb./d.)	(%)	(g./d.)	(%)	(g./d.)	(%)	(g./d.)
5/28/59	First cutting	28.2	61.8	16.7	68.8	—36	17.5	—25	23.3	—12
6/4/59	First cutting	29.4	62.8	18.0	65.1	—23	14.0	—16	38.2	— 4
6/11/59	First cutting	24.5	60.4	14.6	65.0	+15	28.6	— 4	19.5	—12
6/18/59	First cutting	21.6	56.6	13.2	59.4	—14	18.0	—13	12.6	— 9
6/25/59	First cutting	19.2	56.8	14.1	57.6	—16	27.9	— 8	41.9	+ 4
7/29/59	Second cutting	22.3	65.2	21.8	74.3	+71	29.2	+67	46.7	+ 4
8/20/59	Third cutting	21.8	67.8	24.0	75.8	+57	30.3	+67	31.7	— 4

Table 3.—Limited Grain Fed with Soilage, Improved Digestibility and Nutritive Value of the Total Ration

Cutting Dates	Grain fed	Milk Production	Dry Matter Digested	Dig. D.M. 1000 lb. B.W.	Protein Digested	Nitrogen Balance	Calcium Digested	Calcium Balance	Phos. Digested	Phos. Balance
	(lb.)	(lb.)	(%)	(lb./d.)	(%)	(g./d.)	(%)	(g./d.)	(%)	(g./d.)
5/27/59	4.5	36.4	64.7	20.1	68.5	— 1	25.7	— 13	26.6	—11
6/22/59	4.5	27.1	63.6	18.7	64.4	+ 9	41.9	— 5	42.1	+ 3
7/27/59	3.0	29.7	69.3	25.3	76.3	+73	39.4	+109	54.3	+27
5/27/59	0.0	28.2	61.7	16.7	68.8	—36	17.5	— 25	23.3	—12
6/22/59	0.0	19.2	56.8	14.1	57.6	—16	27.9	— 8	41.9	+ 4
7/27/59	0.0	22.3	65.2	21.8	74.3	+71	29.2	+ 67	46.7	+ 4

Table 4.—In Vitro Digestion of Cellulose and Production of Volatile Fatty Acids Compared to In Vivo Cellulose Digestibility and Feed Intake for Various Cutting Dates

Cutting Date	Growth Stage	Dig. Dry Matter Intake per unit metabolic size[1]	Cellulose Digestibility		Nutritive value index[3]	Volatile Fatty Acid Production[2]			
			in vivo	in vitro[2]		Acetic	Propionic	Butyric	Total
		(lb./$W^{.75}$)	(%)	(%)		(mg./g.)	(mg./g.)	(mg./g.)	(mg./g.)
5/28/59	First cutting	.091	67.2	21.3	70.5	55.9	13.9	12.9	82.7
6/4/59	First cutting	.097	67.8	24.4	75.2	69.1	30.8	17.7	117.6
6/11/59	First cutting	091	63.5	20.1	70.5	71.6	17.8	14.7	104.1
6/18/59	First cutting	071	58.0	15.8	55.0	74.2	9.6	11.7	95.5
6/25/59	First cutting	.077	55.1	17.6	59.7	69.7	11.2	18.2	99.1
7/29/59	Second cutting	118	62.4	27.7	91.6	73.7	21.2	24.0	105.2
8/20/59	Second cutting	.129	63.8	28.1	100.0	80.3	23.8	20.3	108.9

[1]Metabolic size=body weight .75 as exponent

[2]Twenty-two hour fermentation **in vitro.**

[3]Method of Crampton **et al.** (7).

Tables 5 and 6 with a description of the individual forages used. In addition, digestible dry matter percent and the digestible dry matter intake for 29 individual cows fed various roughages are presented in Table 7.

APPLICATION OF RESULTS

Cutting dates are the most feasible means presently available for an on-the-farm estimation of the digestibility of forages. Because dry matter digestibility determines the concentration of metabolizable

Table 5.—Dry Matter Digestibility of First Cutting Legume Grass Forage

Material	Cutting Date[1]	Type of Roughage	No. of Trials	Amount of Grain Fed	Total DM Digest-ibility	Forage DM Digest-ibility[2]
				(lb.)	(%)	(%)
Bluegrass	5-14-59	Lawn-clippings	2	0.0	72.4	72.4
Alfalfa-Brome	5-20-60	Chopped hay	4	6.0	67.8	64.1
Alfalfa-Brome	5-20-60	Silage	4	6.0	70.5	67.0
Alfalfa-Brome	5-27-57	Soilage	1	0.0	63.9	63.9
Alfalfa-Brome	5-28-58	Soilage	1	0.0	67.7	67.7
Alfalfa-Brome	5-28-58	Soilage	1	0.0	63.3	63.3
Alfalfa-Brome	5-30-58	Soilage	2	5.0	67.7	64.8
Alfalfa-Brome	6-3-58	Silage	1	0.0	57.8	57.8
Alfalfa-Brome	6-4-59	Soilage	2	0.0	62.8	62.8
Alfalfa-Timothy	6-4-59	Silage	2	2.2	62.0	57.4
Alfalfa-Timothy	6-6-57	Silage	3	7.9	65.8	56.7
Alfalfa-Brome	6-11-59	Soilage	2	0.0	60.4	60.4
Alfalfa	6-11-60	Hay	3	3.5	60.8	59.1
Alfalfa-Brome	6-12-56	Silage	2	0.0	56.0	56.0
Alfalfa-Brome	6-12-58	Silage	1	0.0	56.2	56.2
Alfalfa-Brome	6-13-58	Soilage	2	5.0	65.5	61.8
Alfalfa-Brome	6-16-58	Silage	1	0.0	55.1	55.1
Alfalfa-Brome	6-18-59	Soilage	2	0.0	56.6	56.6
Alfalfa-Timothy	6-24-56	Hay	2	8.4	65.8	58.3
Alfalfa-Timothy	6-24-56	Silage	2	8.3	62.5	54.2
Alfalfa-Brome	6-25-58	Soilage	1	0.0	56.0	56.0
Alfalfa-Brome	6-25-59	Soilage	2	0.0	56.8	56.8
Alfalfa-Brome	6-27-60	Soilage	2	5.0	59.2	55.1

[1]Cutting date is calculated as the middle date of digestion trials when soilage was fed.
[2]In trials where grain was fed, forage DM digestibility was calculated using 86.4 percent as the digestibility of grain dry matter.

Table 6.—Dry Matter Digestibility of Second and Third Cutting Alfalfa

Growth Period	Cutting	Type of Roughage	No. of Trials	Forage D.M. Digestibility
				(%)
32 days	Second	Soilage	1	65.2
39 days	Second	Soilage	2	65.2
46 ± 3 d.	Second	Silage	2	53.6
34 days	Third	Soilage	1	65.1
35 days	Third	Soilage	2	67.8
Unknown	Third	Soilage	1	64.5
Unknown	Fourth	Pellets	1	65.2

energy in forages and likewise is a significant determinant of voluntary consumption, reliable estimates of digestibility are useful in calculating the total energy needs of dairy cows. Except for the digestion coefficients obtained with sheep on hay harvested May 24 and June 16 at Columbus (17), there have been no Ohio experiments relating cutting dates to digestibility. Therefore, a regression of digestibility on growth stage (days after April 30) was computed using the results in Tables 2 and 5. The regression line is shown graphically in Figure 2 and may be described by the formula,

$$\text{(A)} \quad Y\ (\text{digestibility}) = 71.4 - 0.286X$$

where X equals the number of days after April 30. The results are characteristic of those found in the literature (11, 20, 23). In Figure 3, a comparison is made with cutting date regressions obtained by other investigators. The latitudes at which the crops were grown are listed. These suggest that the first growth of plants is only partly controlled by latitude. On the other hand, the close similarity of the Wooster data (41° north latitude) to that obtained at Beltsville (39° north latitude) suggests that to the south of Wooster there is a range of only seven to fourteen days difference in relative digestibility. Thus the results would seem applicable to most Ohio farm conditions where feeding recommendations based on energy intake are sought.

Calculating digestible forage intake. Declining digestibility resulting from advancing cutting dates reduces milk production partly because of lowered concentration of digestible energy and partly because of lowered voluntary consumption. The measurement made in this study that reflects both effects simultaneously is digestible dry matter (D.D.M.) intake. Therefore, it was of interest to find out what relationship existed between digestible feed intake and cutting dates. Because the number of observations in any single experiment were insufficient to compute a reliable regression, the observations from all digestion trials were pooled. Only results obtained with cows fed free choice an all-roughage ration were used.

The digestion coefficients and daily digestible dry matter intakes are listed in Table 7. A regression was computed and the relationship

Table 7.—Digestible Dry Matter Percent and Digestible Dry Matter Intake in Individual Cows Fed Various Forages

Forage	Dry Matter Digestibility	Digestible Dry Matter Intake
	(%)	(lb./day/1000 lb. of body wt.)
Alfalfa	68.9	23.2
Alfalfa-Brome	67.7	22.4
Alfalfa	66.7	24.5
Trefoil-Ladino	66.4	20.8
Alfalfa	65.5	21.3
Alfalfa	65.2	22.7
Alfalfa	65.1	22.3
Alfalfa	64.9	22.0
Alfalfa	64.5	21.2
Alfalfa-Brome	63.9	15.2
Alfalfa	63.7	22.3
Alfalfa-Brome	63.3	17.3
Alfalfa-Brome	62.7	19.2
Timothy-Ladino	62.3	21.4
Alfalfa-Brome	60.2	16.1
Alfalfa-Brome	58.8	15.4
Timothy-Ladino	58.6	12.5
Alfalfa-Brome	57.8	12.2
Alfalfa-Brome	57.4	10.8
Orchardgrass	56.8	17.3
Timothy-Ladino	56.8	14.0
Timothy-Ladino	56.4	12.3
Alfalfa-Brome	56.2	13.3
Alfalfa-Brome	56.0	17.8
Alfalfa-Brome	55.1	16.6
Alfalfa-Brome	54.6	11.1
Alfalfa	53.8	10.9
Alfalfa	53.4	14.8
Reed Canary Grass	48.7	9.9

between feed intake is described by the formula,

$$\text{(B)} \quad Y \text{ (DDM intake)} = 0.741X - 27.5,$$

where X is equal to the digestibility. In turn this formula was combined with formula (A), Y (digestibility) = 71.4 − 0.286X as follows:

$$Y \text{ (DDM intake)} = 0.741 \ (71.4 - 0.286X) - 27.5$$

$$Y \text{ (DDM)} = 25.4 - 0.212X$$

where X = cutting dates after April 30.

The latter formula provides a basis for predicting the average digestible dry matter intake of cows fed first-cutting legume-grass forages grown in Central Ohio and harvested on dates between May 17 and June 30. In order to illustrate the suitability of these data for use in estimating the energy intake of cows, an attempt was made to calculate the net energy value of forages of various levels of digestibility according to the procedure described by Reid (22). The calculated

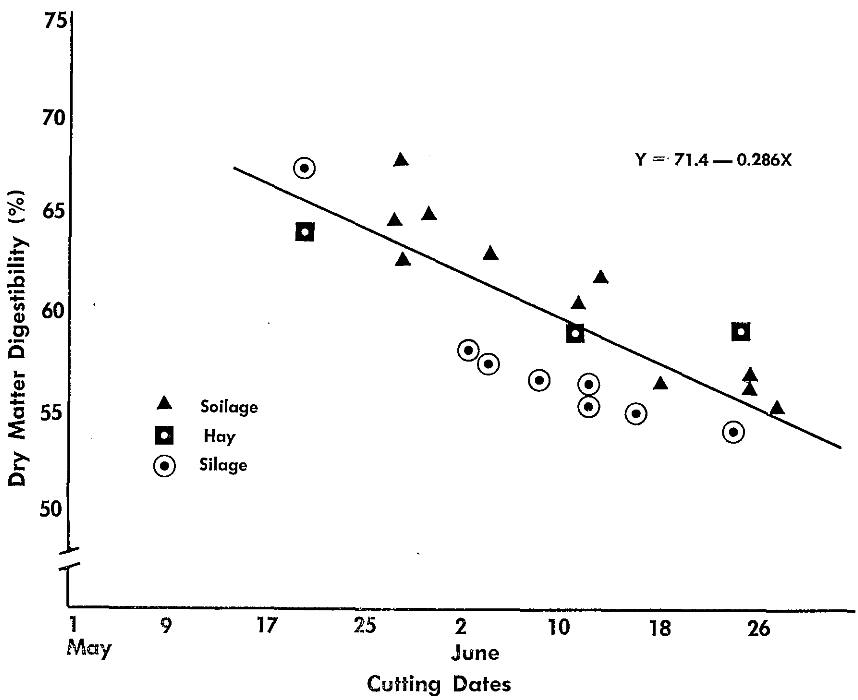

Fig. 2.—The Regression of Legume-Grass Forage Dry Matter Digestibility on Cutting Dates.

net energy in the forages[1], the regression of digestible dry matter on cutting dates, and the milk production for the 12 cows in Experiment 1 for the period May 19 to June 29 are highly correlated as shown in Figure 4. In fact, a correlation coefficient of 0.9998 was obtained for the correlation of the average daily milk production of the 12 cows used in Experiment 1 with the average daily digestible dry matter

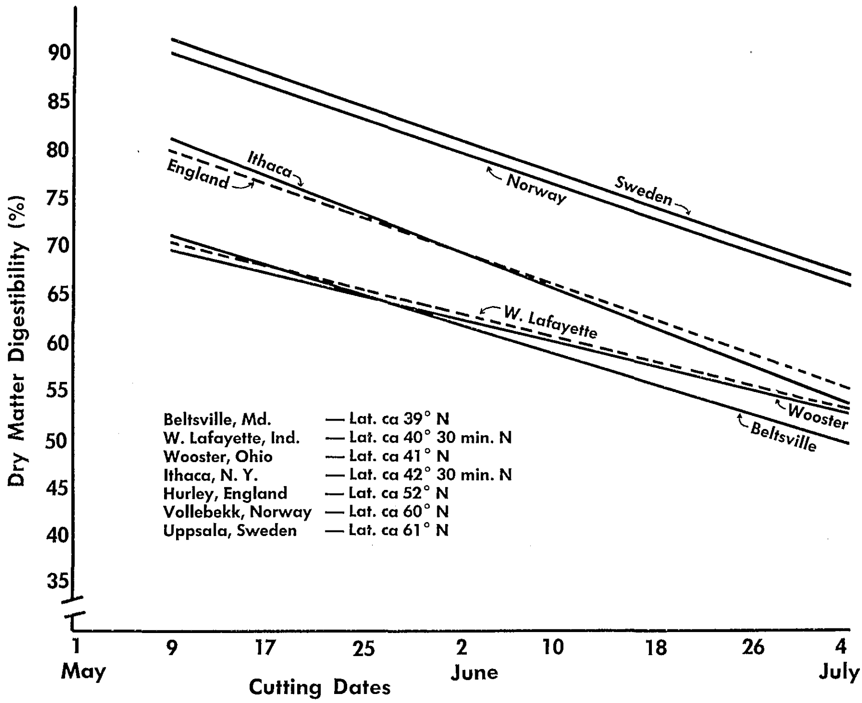

Fig. 3.—Relationship Between Cutting Time and Digestibility of Forages at Various Latitudes in Several Countries. Partly Adapted from Reid et al. (23).

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[1]The true net energy value of a specific feed is variable. The calculation is only an index because of the variable interaction of energy requirements with the contingencies of practice such as the effects of climatic variation on quality of other feeds, associative digestibility of feeds, and variations in the digestive, assimilative and metabolic individuality of the animals. There are no standard conditions of practice for determining the net energy values which apply under farm conditions where such effects are known to exist [see Swift **et al.** (24)]. Hence, further discussion in this paper deals only with the digestible dry matter intake.

intake per unit of metabolic size for each of the weekly cutting dates as determined from the formula,

$$Y = 25.4 - 0.212X \text{ (Table 8).}$$

The predicted amount of digestible dry matter in forages for various cutting dates, the amount of digestible dry matter that should be furnished from grain and the amount of grain needed have been calculated and are shown in Table 9.

Optimum time to cut. Optimum time to cut forages is determined by the general axiom that degree of animal response is governed by the energy intake; often they have been equated (23). A basis for deciding when to cut first growth forages may be obtained by multiplying the average digestible dry matter percent by the plant yields for the respective cutting dates to obtain what is recognized as the

Table 8.—Correlation Coefficients

	Variables Correlated	No. of Means Compared	Coefficients r	Coefficients r^2
1.	Average daily milk production (4% FCM) of 12 cows in experiment 1 with the average daily digestible dry matter per unit of metabolic size calculated from all trials (Y=25.4—0.212X).	7	0.9998	0.9996
2.	**In vitro** cellulose digestibility with average daily digestible dry matter intake, experiment 1, Tables 2 and 4.	7	0.9654	0.9320
3.	**In vitro** cellulose digestibility with the log of the average daily dry matter intake, experiment 1, Tables 2 and 4.	7	0.9786	0.9577
4.	**In vitro** cellulose digestibility with average percent dry matter digestibility, experiment 1, Tables 2 and 4.	7	0.9743	0.9473
5.	**In vitro** cellulose digestibility with the calculated nutritive value index, experiment 1, Table 4.	7	0.8623	0.7435
6.	**In vitro** cellulose digestibility with the digestible dry matter intake per unit metabolic size, experiment 1, Table 4.	7	0.8623	0.7435
7.	**In vitro** cellulose digestibility with the average daily milk yield, experiment 1, Tables 2 and 4.	5	0.8800	0.7744
8.	**In vitro** cellulose digestibility with digestible dry matter percentage, experiment 1, Tables 2 and 4.	7	0.7319	0.5340

energy-yield index. For purposes of illustration, this was done using Willard's 14-year average yields for first growth alfalfa, disregarding possible intrastate differences in the slope of the digestibility curve for crops grown at Columbus as compared to Wooster (25). The greatest energy-yield or the time when the most digestible dry matter was obtained is shown in Table 9 as June 7 and 14. The optimum time to harvest forages however, represents a compromise among the simultaneous effects of maximum nutrient yield, decreasing digestibility, and either additional grain requirements or lowered milk yields.

One problem encountered in delaying the date of harvesting forages is the rapid decline in milk yield (Figure 4) so that an increasing amount of grain must be fed with the forage if milk production is to be maintained near the maximum possible for cows in adequate nutrition. Also contingent on the cutting date of first growth are the forage yields obtained from second, third and possibly fourth cuttings

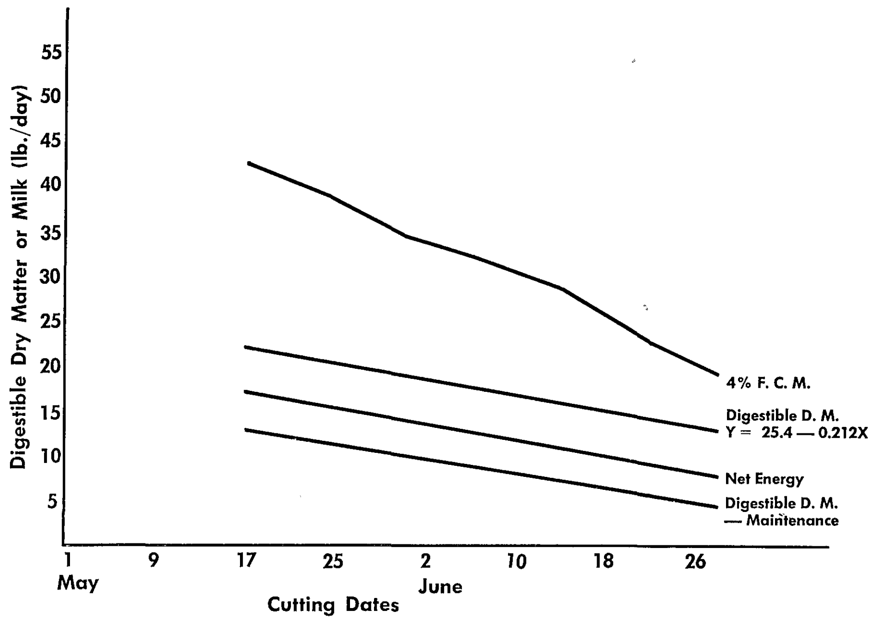

Fig. 4.—The Relationship Between Cutting Dates of First Growth Forage and (1) Amount of 4 percent FCM Produced, (2) Average Daily Digestible Dry Matter Consumed per 1000 pounds of Body Weight, (3) Average Daily Digestible Dry Matter Minus the Maintenance Requirement, and (4) the Calculated Net Energy Value of the Forage Assuming that 69.3 percent of the Absorbed Energy was Used for Productive Purposes.

Table 9.—The Calculated Nutrient and Milk Yields, the Amount of Grain Required and Dry Matter Yields of Second and Third Cuttings for Alfalfa Forages on Various Cutting Dates. Part of the data obtained from Willard's summary tables (25).

Cutting Date	Dry Matter Digestibility[1]	Digestible Dry Matter[2]	Amount of Grain Required[3]	2nd and 3rd cutting dry matter[4]	Cow-days from first growth[5]	Total cow-days[5]	Theoretical Milk Yield[6]
	(%)	(lb./acre)	(lb./day)	(lb./acre)	(per acre)	(per acre)	(lb./acre)
May 17	66.5	1961	5.0	5220	89.1	235.2	8286
May 24	65.0	1995	7.6	5100	98.2	241.0	7719
May 31	62.5	2224	9.5	4610	118.2	247.0	7410
June 7	60.5	2486	11.5	4760	142.8	276.6	7505
June 14	58.5	2491	13.4	4610	156.6	286.6	7224
June 21	56.6	2388	15.4	4690	165.8	298.3	6982
June 28	55.0	2387	17.8	2510[7]	198.9	269.1	6197

[1]From the regression equation $Y = 71.4 - 0.286X$, where X is equal to days after April 30.

[2]First growth data for alfalfa, Agronomy Handbook, Table 131 (25).

[3]The amount of supplemental grain feeding that would be required to keep the cows in optimum production.

[4]Yields for second and third growth obtained, Agronomy Handbook, Tables 128 and 132 (25), by subtracting first cutting yield from average total yield and extrapolating for May 17 and 24.

[5]Cow-days equals total digestible dry matter per acre divided by maximum forage intake in lb./d./1000 lb. of body weight.

[6]Based on an average daily milk production of 42.6 lb. of 4 percent FCM and added grain to maintain milk production. Grain acreage included as corn at the production level of 100 bushel per acre.

[7]Second cutting is the only aftermath cutting possible if September 10 is set as the last safe cutting date in the autumn.

which decrease with advancing cutting dates and the amount of forage produced per acre in terms of cow-days which increases with advancing cutting dates. A more realistic basis for making a judgment on the optimum time to cut forages than the energy-yield index provided in Table 9 may be obtained if all the known factors that affect yield per acre are considered. The values for the known effects were calculated from the experimental data or obtained from summaries of Willard's results (25). They are included in Table 9. These data were used to calculate the milk yield per acre. Milk yield per acre makes a useful tool for deciding the optimum time to harvest alfalfa-grass forages and shows the advantages of early cutting, that is, high digestibility and more aftermath production. Thus, the target dates for harvesting first cutting forage would be the weeks of May 17 or May 25 depending on whether it is a new seeding or an old seeding which will be plowed down. In terms of percent digestibility, forages should be harvested previous to or by the time they are 63 percent in digestible dry matter, if most of the effects of plant maturity are to be avoided. The dry matter digestibilities for various lines of latitude in Ohio are shown in Figure 5.

Meadow crops for silages should be cut earlier. The digestion coefficients obtained with the alfalfa-brome silages emphasize the importance of ensiling legume-grass meadows before June 1. It will be noted in Figure 2, even though there are only seven values, that the silage digestion coefficients fell distinctly below the values for soilage and hay for the same cutting dates except in the case of a silage harvested on May 20. It was observed that the dry matter losses of part of these silages ranged from 15 to 27 percent. Therefore, it is concluded that the nutrients lost in fermention and from seepage included those most readily available so that the remaining forage contained a greater proportion of indigestible matter. On the other hand, even though the silage harvested in May undoubtedly experienced some losses, that part which remained was approximately as digestible as the portion lost; therefore, in this case digestibility was not lowered by the ensiling process and it was advantageous to cut for silage early.

Second and third cuttings. The second and third cuttings were highly digestible when allowed to grow for periods up to six weeks but in one case decreased markedly during the seventh week. Thus it is concluded that the optimum time for cutting second and third growth of alfalfa is 39 days. This is in congruence with present agronomic recommendations for obtaining optimum yields.

***In vitro* digestibility.** The *in vitro* cellulose digestion rate was highly correlated with the actual dry matter digestion coefficients obtained for the forages (Table 8). Likewise there was good correlation with digestible dry matter intake and milk production. These data corroborate and augment the findings of Donefer *et al.* (10). The correlation of the *in vitro* cellulose digestibility with the average daily dry matter intake per 1000 lb. of body weight resulted in a correlation coefficient, $r = 0.9654$, which is higher than the 0.91 obtained by Donefer *et al.* (10). Moreover, when the data were rectified by using the log of the digestible dry matter intake, the correlation coefficient became 0.9786. This accounted for 95.8 percent of the total variability in digestible dry matter intake. Obviously the limited results presented here do not constitute a basis for formulating a general relationship between *in vitro* digestibility and the nutritive value of forages, but the

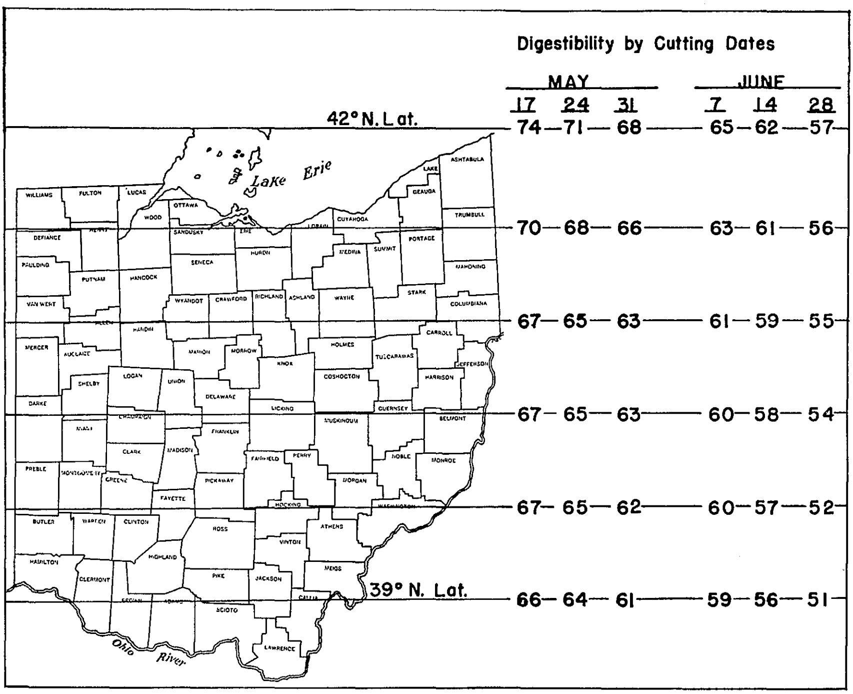

Fig. 5.—In the Accompanying Map of Ohio, Lines of Latitude at 40-mile Intervals are Shown with Estimation of Dry Matter Digestibilities for Six Cutting Dates. Part of these data were Interpolated Based on the the Results of the Experiments Carried out at Wooster, Cornell University, Ithaca, New York, and the U.S.D.A., Beltsville, Maryland.

correlations listed in Table 8 illustrate that the artificial rumen procedure will be useful for predicting the nutritive value on various cutting dates of mixed forages. Nutritive value index and digestible dry matter intake are highly related terms. The nutritive value index shown in Table 4 and correlated with *in vitro* cellulose digestibility in Table 8 is synonymous with the digestible dry matter intake per unit metabolic size because the maximum forage intake which happened to be that for the August 20 cutting was used as the maximum expected standard forage intake in the nutritive index calculation. A significant correlation, $r = 0.732$, was obtained between *in vitro* propionic acid production and *in vivo* dry matter digestibility.

Nitrogen, calcium and phosphorus balances. An extended discussion of the nitrogen picture will be omitted at this time since the data are published elsewhere (6). However, it should be noted that digestible protein equivalent like total digestible dry matter declined with advancing cutting dates, Figure 1. This was caused by lower feed intake, lower nitrogen avilability, lower percentage nitrogen in the forages and consequently lower percentage nitrogen digestibility. It is of considerable practical importance to note with regard to the first three digestion periods shown in Table 2, that the cows were in negative nitrogen balance because of the lack of digestible nutrients despite adequate total protein in the ration. This illustrates the importance of maintaining optimum feed intake.

Although calcium intake was in line with National Research Council recommendations (19), the cows digested very small proportions of the calcium present in the forage and remained in negative calcium balance throughout the first five trials of the experiment. Digestion improved once the cows were shifted to the second cutting high calcium alfalfa. Calcium retention rates raised to unusually high amounts. These findings demonstrate the need for calcium supplementation when mixed forages are fed and particularly when late cut mixed forages are used.

Phosphorus intake was less than requirements in all forages fed resulting in rather continuous negative phosphorus balance. Thus, phosphorus, always a major nutrient requirement by dairy cows, should be fed liberally with all types of forage rations. It may be desirable to raise the level of phosphorus supplement (bone meal, defluorinated rock phosphate, or dicalcium phosphate) to 2 percent of the grain mixture if limited amounts of grain are being fed with very high quality roughages or provide for an increased amount of time when free choice phosphorus supplements are available.

In conclusion, it is emphasized that the restriction on nutrients caused by maturation of the plants and represented by advancing cutting dates of first growth forages induced or increased the severity of deficiencies of carbohydrates for energy, protein, calcium, and phosphorus and the deficiencies were shown to markedly reduce milk production.

SUMMARY

Digestibility, feed intake, milk production, and nitrogen, calcium and phosphorus balances were determined in conjunction with forage utilization studies in an attempt to evaluate the effects on nutritive value of advancing maturity and length of growing period. Eighty-three digestion trials were carried out over a 5-year period. The forages used were primarily alfalfa-brome mixtures.

Using results of 23 digestion trials obtained with cows fed legume-grass forages, dry matter digestibility was found to decrease by approximately two percentage units per week and was expressed by the regression formula, Y (digestibility) $= 71.4 - 0.286X$ where X is equal to the number of days after April 30. The regression formula for decline in daily digestible dry matter intake from first growth legume-grass forages among cows fed all roughage rations was Y (digestible dry matter) $= 25.4 - 0.212X$. These formulae provide a basis for predicting the nutritive value of first-cutting forages in central Ohio. The daily digestible dry matter intake per unit body weight was highly correlated with milk production indicating that these formulae are highly useful for making on-the-farm estimations of the value of forages.

When second and third-cutting yields were included, maximum yield of milk per acre was calculated to result from the earliest cut forages (May 17 and May 24 in this study). Digestibility of second growth alfalfa declined markedly after a 42-day growing period.

The *in vitro* cellulose digestibility was highly correlated with dry matter digestibility, digestible dry matter intake, and milk production. *In vitro* propionic acid production was correlated with dry matter digestibility. These results indicate that the artificial rumen procedure also will be useful for predicting the nutritive value on various mixed forages.

It was concluded that the maturing of plants, represented by advancing cutting dates of first growth, induced or increased the severity of deficiencies of carbohydrates (for energy), protein, calcium and phosphorus and this combination of deficiencies was found to markedly reduce milk production.

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